Mechanical Systems and Signal Processing xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Acoustic emission signal processing for rolling bearing running state assessment using compressive sensing

Chang Liu [a,*], Xing Wu [a], Jianlin Mao [b], Xiaoqin Liu [a]

[a] *Faculty of Mechanical & Electrical Engineering, Kunming University of Science & Technology, Kunming 650093, China*
[b] *Faculty of Information Engineering & Automation, Kunming University of Science & Technology, Kunming 650093, China*

ARTICLE INFO

Article history:
Received 19 December 2015
Received in revised form 24 November 2016
Accepted 5 December 2016
Available online xxxx

Keywords:
Acoustic emission
Compressive sensing
State assessment
Compressive feature

ABSTRACT

In the signal processing domain, there has been growing interest in using acoustic emission (AE) signals for the fault diagnosis and condition assessment instead of vibration signals, which has been advocated as an effective technique for identifying fracture, crack or damage. The AE signal has high frequencies up to several MHz which can avoid some signals interference, such as the parts of bearing (i.e. rolling elements, ring and so on) and other rotating parts of machine. However, acoustic emission signal necessitates advanced signal sampling capabilities and requests ability to deal with large amounts of sampling data. In this paper, compressive sensing (CS) is introduced as a processing framework, and then a compressive features extraction method is proposed. We use it for extracting the compressive features from compressively-sensed data directly, and also prove the energy preservation properties. First, we study the AE signals under the CS framework. The sparsity of AE signal of the rolling bearing is checked. The observation and reconstruction of signal is also studied. Second, we present a method of extraction AE compressive feature (AECF) from compressively-sensed data directly. We demonstrate the energy preservation properties and the processing of the extracted AECF feature. We assess the running state of the bearing using the AECF trend. The AECF trend of the running state of rolling bearings is consistent with the trend of traditional features. Thus, the method is an effective way to evaluate the running trend of rolling bearings. The results of the experiments have verified that the signal processing and the condition assessment based on AECF is simpler, the amount of data required is smaller, and the amount of computation is greatly reduced.

1. Introduction

In the rotating machinery, rolling bearings are widely used in the rotating machinery, while they are also easily damaged components. Vibration analysis is common and reliable technique, and has been applied to condition monitoring in many applications. Various techniques based on vibration analysis have been validated, such as time-analysis, frequency analysis, wavelet analysis and singular value decomposition [1,2]. Acoustic emission (AE) is an effective method to condition monitoring of the rolling bearing. In comparison to vibration analysis, AE signal is more sensitive and can detect early defect [3]. Balerston applied the AE technology to identification defects in rolling element bearing. This is one of the earliest applications of AE to monitoring bearings [4]. Mba presents a review about the application of AE technology to condition monitoring

* Corresponding author.
E-mail address: liuchang3385@gmail.com (C. Liu).

http://dx.doi.org/10.1016/j.ymssp.2016.12.010
0888-3270/

[5]. Khamis present the energy index technique of AE for early defects detection of bearing [6]. However, limitations in the application of AE technique for monitoring the bearing have been due to the difficulty in acquiring, processing, and saving the acquired data. There is AE signal analysis requires very high sampling frequency, and very big sampled data set. It is known that high sampling frequency will lead to challenges for selecting sampling hardware with increased costs. At the same time, large sampling data also creates difficulties for data storage, transmission and analysis.

To address the above issues, compressive sensing (CS) [7–9] can be used as a useful technique. Compressive sensing states that one sparse signal can be sensed by fewer measurements than sampling it at the Nyquist rate. The signal can then be reconstructed with high probability by solving the optimization problem [10]. Compressive sensing is a new signal acquisition theory. Based on the CS theory, for any signal that is sparse, it can be sensed with far less points than points obey by the sampling theorem. This process can be called as compressive sampling. The original signal can be recovered from the compressively-sensing data. In this sense, the compressively-sensing data contains sufficient information of original signals. Wang proposed PFPDA algorithm for reconstruction of sparse time-frequency representation from noisy compressively-sensing data [11]. Yuan proposed a reconstruction-evaluation based fault diagnosis method with compressed signals [12]. Shoaib proposed a methodology for advance inference on sensor nodes by using a patient-specific seizure detection algorithm base on electroencephalogram (EEG) sensing [13]. The method directly uses compressively-sensed signals for inference on sensor nodes. Ref. [14] describes an approach that enables efficient representation based on sparsity to be utilized throughout signal processing system to reduce the energy and resources required for computation, communication, and storage. Calderbank investigated theoretical bounds for signal classification using compressively-sensed data in the compressed domain [15]. In this paper, we introduce CS to analyze the AE signal and focus on extracting compressive features for compressively-sensed data.

In this paper, we focus on two key problems: the processing of AE signal based on CS, and the assessing conditions of the rolling bearing based on AE compressive feature. In order to solve first problem, we prove the sparsity of AE signal of the rolling bearing. Then we acquire the compressively-sensed data and finally recover the original signal from those data. It proves that the compressively- sensing data contains sufficient information of original signals. Then we study how to use the information hidden in compressively-sensed data to address second problem. We obtain the energy of compressively-sensed data. We prove that the energy of signal can be preserved under random projection. Then, we can use the energy of compressively-sensed data as a feature for analysis, instead of the energy of original signal in the time domain. There are common features based on energy of signal in the time domain, such as RMS and variance. We prove that the feature based on the energy of compressively-sensed data is equivalent to those features based on the energy of signal in the time domain. The feature based on the energy of compressively-sensed data is called as compressive feature due to the processing is done in compression domain. The analysis based on compressive feature is simpler because the amount of data required is smaller, while the amount of computation is reduced. Our specific contributions are as follows:

- To prove there are enough information in compressively-sensed data, we recover the original signal from compressive-sensed data. Through carefully selected compression rate, we get less compressively-sensed data and lower reconstruction error.
- We want to work directly with the compressively-sensed data for analysis. We demonstrate the energy preservation properties and the energy of the compressively-sensed data are equivalent to the energy of the Nyquist sampling data. Then we obtain compressive feature based on the energy of the compressively-sensed data.
- It is a challenge to analysis using compressive feature of AE signal. The feature trend of the bearing indicates the change tendency and the current stage of the life cycle. We prove that the AECF trend is consistent with the trend of common features.

As mentioned above, a method of extraction AE compression feature (AECF) is proposed. We describe the processing of the extracted AECF feature from compressively-sensed data directly. We use the AECF trend for monitoring and evaluation of the rolling bearing running state. Research results show that the AECF trend of the running state of rolling bearings is consistent with the trend of traditional features. The method is an effective, saving way to evaluate the running trend of rolling bearings.

A brief overview of this paper is as follows: Section 2 provides background of CS theory and AE signal. Section 3 demonstrates the AE signal processing and AECF compressive feature extraction. Section 4 is the experimental verification. Section 5 concludes the paper.

2. Background

This section will briefly introduce the basis of the acoustic emission signal and compressive sensing theory, which will be used in the following development.

2.1. Acoustic emission signal

AE signals is kind of elastic stress waves generated by the fault structural. Under the external force, plastic deformation, fracture or irreversible deformation inside the solid materials will release AE signal. For instance, the formation of subsurface